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PROJECT HELIOS
INVESTIGATION OF ADHESIVES WITH RESPECT TO HEAT RESISTANCE AND WEIGHT

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ABSTRACT. Solar battery components were cemented with a series of American and German curable adhesives and tested under severe time and temperature conditions approximating those that would be encountered by such components in space. Those components were tested after cementing both by peeling and by tension vertical to the flat surface. The Dow Corning product XR-63-489 proved to be the preferred adhesive for reasons of strength, processability, and elasticity.

1. INTRODUCTION /7*

In conjunction with the special problems associated with Project Helios (solar probe), AEG - Telefunken was engaged by the Society for Space Research, Ltd. to carry out tests in the area of the phase C study on solar cell modules as well as the individual components such as solar cells, contacts and adhesives with respect to temperature resistance and (partly) irradiation at high solar intensity.

This report presents the studies that deal especially with the mechanical characteristics of various adhesives following exposure to high temperatures.

2. Selection of Adhesives /8

2.1. Preliminary Selection of Adhesives

The adhesives contained in the specifications were selected for their promising suitability on the basis of AEG - Telefunken's experience.

Preliminary tests were performed with the following adhesives, in order to determine the optimum preliminary treatment of the samples and to ascertain the appropriate primers:

- Dow Corning XR-63-489;
- Dow Corning Silastic S 2288;
- Wacker E 33;
- Thermo Resist TR 150-25;
- General Electric RTV 602.

*Numbers in the margin indicate pagination in the foreign text.

The General Electric RTV 560/580 adhesive used in the AZUR program could not be tested with the others because no fresh adhesive was available owing to

40 a strike at the manufacturer, and the supplies on hand were too old.

In the case of all the adhesives, the preliminary tests involved mainly the determination of the optimum adhesion method. Basically, only the peel test described in Section 3.2 was used.

Only polimide foil (Kapton, from DuPont) was used as the substrate, while anodized aluminum was the panel material.

Additional preliminary tests were performed on XR-63-489 adhesive to achieve maximum adhesion to Kapton. Various primers were available to choose from, to find the one with the best adhesion. Three types of pretreated Kapton foil were used to study the strength of the XR-63-489 adhesive.

a). sandblasted and cleaned with solvent /9

b). roughened with Ata and cleaned with solvent

c). cleaned only with solvent

The preliminary tests were carried out with samples for which all primers were used on each Kapton pretreatment.

The Dow Corning Primer 4094 proved to be the most suitable on the basis of the preliminary tests with adhesive XR-63-489. The best results for the Kapton pretreatments were obtained on Kapton roughened with Ata.

Results in the preliminary test:

Peel test: 0.4-0.6 Kg-force per 1" width.

Good processability (very slight viscosity)

The adhesive TR 150-25 of the Thermo Resist Corp. which was selected originally because of its good adhesion to Kapton, was eliminated in the preliminary test because it required a high contact pressure for blister-free curing, which was not usable in solar battery processing. For this reason it was eliminated form the specification and replaced with S 2288 plus 10% A 4,000, both by Dow Corning.

These adhesives showed the highest peel strength at room temperature in the preliminary tests, so that it was chosen for the adhesive of the couplet sample model according to item 12.3 of the specification.

Results in preliminary test:

Peel test: 2.5-3.5 Kg force on 1" width

2.2. OPTIMUM METHOD OF ADHESION /10

2.2.1. ADHESIVES FOR COVERGLASS-BATTERY

a). XR-63-489 Dow Corning

Adhesive XR-63-489)
Catalyst XR-63-489) Dow Corning
Primer 6-3466)
Cleaning alcohol)

The cover glasses were primed with 6-3466 primer and air-dried at room temperature for about two hours.

The XR-63-489 cover glass adhesive was mixed with 10% XR-63-489 hardener, degassed at about 1 Torr, placed in a syringe and again degassed. The application of the adhesive to the battery was by a proportioning arrangement which allowed an exact reproduction of the amount of adhesive. The cover glasses were placed under a microscope after the adhesion, degassed at about 1 Torr and finally cured in an oven at 150°C for two hours.

b). RTV 602 cover glass adhesive (General Electric)

RTV 602 adhesive)
SRC-05 hardener) General Electric
6-3466 primer ÷ Dow Corning
Purification solvent

The cover glasses were primed with Dow Corning primer 6-3466 adhesive.

The RTV 602 adhesive was treated with 0.5% addition of General Electric SRC-05 hardener. The processing and curing is the same for this adhesive as for Dow Corning XR-63-489 cover glass adhesive.

2.2.2. ADHESIVES FOR BATTERY-SUBSTRATE /11

a). XR-63-489-Dow Corning)

XR-63-489 adhesive) Dow Corning
XR-63-489 catalyst)
4094 primer)

The samples are cleaned with solvent. The Kapton is roughened with Ata before cleaning and priming. The degassed adhesive is then applied to the metal samples by spray, in order to avoid any blister formation. The Kapton strip provided with a gripping clip is then applied. Curing of the adhesive is in an oven at 150°C for two hours.

b). Elastosil 33 of Wacker-Chemie

Elastosil 33 adhesive)

Primer FD (primer, colorless)) Wacker-Chemie

Cleaning agent: solvent

Cleaning of the samples with solvent, primed with Primer FD, the Wacker-Chemie primer.

E 33 adhesive was applied to one side of the sample 0.1 mm thick with spatula and template. One must be careful to close the adhesive tube at once after use, since otherwise the adhesive would harden. The lumps which then form would be disturbing during application by scoring.

The curing time for E 33 is about one week at room temperature; however, its greatest strength is developed after four weeks at room temperature.

c). TR 150-25 of Thermo-Resist Coup. /12

TR 150-25-Thermo-Resist

Cleaning agent: solvent

The samples are cleaned with solvent. A primer was not used; the adhesive was applied with a brush. The adhesive had to be evaporated at 90°C for ten minutes before joining the samples. The samples were pressed together with a roller after cementing together. The adhesive application was to one side.

Curing took place at 177°C for one hour, followed by 204°C for one hour. The adhesive had to be maintained under a pressure of about 3 sc-force/cm^2 during curing, so that blisters would not form. This adhesive was only investigated in the preliminary tests.

d). S 2288 with 10% A 4,000, Dow Corning

S 2288 adhesive)

A 4,000 adhesive) Dow Corning

Cleaner: solvent

1,200 primer) Dow Corning

2.2.3. ADHESIVE FOR SUBSTRATE-PANEL

The cementing was carried out with the same adhesives as for 2.2.2.

3. EXPERIMENTAL PROCEDURE

3.1. TYPE OF ADHESIVE SAMPLES

TABLE 1. REVIEW OF THE SILICON ADHESIVES USED /15

Adhesive for	Sample type	Adhesive			Test conditions
Panel/ Substrate	Al/Kapton	30 samples XR-63-489	30 samples E 33	30 samples S 2288	Peel test
Substrate/ Solar battery	Kapton/Silver	22 samples XR-63-489	22 samples E 33	22 samples S 2288	Peel test
	Kapton/ Solar battery	15 samples XR-63-489	15 samples E 33	15 samples S 2288	End pull test
Supplier		Dow Corning	Wacker	Dow Corning	

Optical adhesive for	Sample type	Adhesive		Test conditions
Solar battery/ Coverglass	Glass/ Glass	30 samples XR-63-489	30 samples RTV 602	End pull test
	Solar battery/ Coverglass	30 samples XR-63-489	30 samples RTV 602	End pull test
Supplier		Dow Corning	General Electric	

Table 1 gives a survey of the adhesives used and the conditions of testing. The end pull test was chosen for cementing with rigid solar batteries and cover glasses; for this test the demand is for the force to be applied perpendicular to the whole 2 cm x 2 cm adhesive surface. For samples with substrate, for which the only partly mechanically roughened Du Pont polyinide film Kapton was chosen because of the temperature requirements, the peel test was applied, for which the force is a live stress over a sample width of 25 mm. The preliminary tests had shown that more differentiated strength values are shown in this case than for the end pull test with its high forces active over the total surface.

The preparation of individual samples was by the procedure of cementing, described in Section 2.2.

3.2. TEST CONDITIONS /16

The cemented samples were subjected to the following [illegible] rising temperatures, approximating the temperature-time profile of the solar probe mission.

24 hours at -80°C
75 hours at +90°C
150 hours at +120°C
300 hours at +150°C
115 hours at +180°C

The application took place under protective gas at -80°C under atmosphere conditions for the positive temperatures. After the individual temperature tests, for a total of 30 samples, four samples were removed after each temperature, for 22 samples, three samples each, and for 15 samples, two samples were removed and tested for strength.

4. TEST RESULTS /17

4.1. ADEHSIVES FOR CEMENTING KAPTON ON ALUMINUM

Test: Peel test

Sample Size: 25 mm wide Kapton strips on 30 mm wide, 5 mm thick aluminum 60 mm long

Test value: Result in Kg force per 2.5 cm peel width.

Adhesive: XR-63-489 with 10% hardener (Figure 1).

a).	pre-storage test - average adhesive strength				0.55 Kg
b).	after 24 h - 80°	"	"	"	0.40 Kg
c).	after 75 h + 90°	"	"	"	0.31 Kg
d).	after 150 h+120°	"	"	"	0.27 Kg
e).	after 300 h+150°	"	"	"	0.22 Kg
f).	after 115 h+180°	"	"	"	0.28 Kg

Adhesive: E 33 (Figure 2).

a).	pre-storage test - average adhesive strength				2.35 Kg
b).	after 24 h - 80°	"	"	"	2.85 Kg
c).	after 75 h + 90°	"	"	"	2.92 Kg
d).	after 150h +120°	"	"	"	3.40 Kg
e).	after 300h +150°	"	"	"	2.40 Kg
f).	after 115h +180°	"	"	"	4.15 Kg

Adhesive: S 2288 with 10% A 4,000 (Figure 3).

a).	pre-storage test - average adhesive strength				4.10 Kg
b).	after 24 h - 80°	"	"	"	3.70 Kg
c).	after 75 h + 90°	"	"	"	4.25 Kg
d).	after 150h +120°	"	"	"	4.27 Kg
e).	after 300h +150°	"	"	"	2.75 Kg
f).	after 115h +180°	"	"	"	1.98 Kg

4.2. ADHESIVES FOR CEMENTING OF SILVER ON KAPTON /18

Test: Peel

Sample size: 25 mm wide Kapton strip on 30 mm wide, 3 mm thick silver 60 mm long.

Test value: Result in Kg force per 2.5 cm peel width.

Adhesive: XR-63-489 with 10% hardener (Figure 4).

a).	pre-storage test - average	adhesive	strength		0.70 Kg force
b).	after 24 h - 80°	"	"	"	0.84 Kg
c).	after 75 h + 90°	"	"	"	0.82 Kg
d).	after 150h +120°	"	"	"	0.84 Kg
e).	after 300h +150°	"	"	"	0.50 Kg
f).	after 115h +180°	"	"	"	0.34 Kg

Adhesive: E 33 (Figure 5).

a).	pre-storage test - average	adhesive	strength		3.15 Kg
b).	after 24 h - 80°	"	"	"	0.30 Kg
c).	after 75 h + 90°	"	"	"	4.84 Kg
d).	after 150h +120°	"	"	"	3.90 Kg
e).	after 300h +150°	"	"	"	4.90 Kg
f).	after 115h +180°	"	"	"	4.24 Kg

Adhesive: S 2288 with 10% A 4,000 (Figure 6).

a).	prestorage test - average	adhesive	test		4.15 Kg
b).	after 24 h - 80°	"	"	"	3.70 Kg
c).	after 75 h + 90°	"	"	"	4.26 Kg
d).	after 150h +120°	"	"	"	4.47 Kg
e).	after 300h +150°	"	"	"	2.37 Kg
f).	after 115h +180°	"	"	"	2.00 Kg

4.3. ADHESIVE FOR CEMENTING OF SOLAR BATTERIES TO KAPTON /19

Test: End Pull

Samples: A T-section to initiate the text forces was cemented on the solar battery dummy and opposite on the Kapton back side.

Test value: Result in Kg force per 4 cm^2 battery dimension.

XR-63-489 adhesive with 10% hardener (figure 7).

a).	pre-storage test - average	adhesive	strength		12.00 Kg
b).	after 24 h - 80°	"	"	"	20.00 Kg
c).	after 75 h + 90°	"	"	"	20.25 Kg
d).	after 150h +120°	"	"	"	20.50 Kg

Adhesive: E 33 (figure 8).

a).	pre-storage test - average	adhesive	strength		23.00 Kg
b).	after 24 h - 80°	"	"	"	25.50 Kg
c).	after 75 h + 90°	"	"	"	15.00 Kg
d).	after 150h +120°	"	"	"	22.50 Kg
e).	after 300h +150°	"	"	"	24.00 Kg
f).	after 115h +180°	"	"	"	39.75 Kg

4.4. ADHESIVES FOR CEMENTING OF GLASS ON GLASS /20

Test: End Pull Test

Sample: T-sections were cemented onto the opposite glass surfaces in order to transfer the test loads to the specimens.

Test value: Result in Kg force per 4 cm^2 sample size.

Adhesive: XR-63-489 with 10% hardener (Figure 9).

a).	pre-storage test - average	adhesive	strength		55.25 Kg
b).	after 24 h - 80°	"	"	"	57.25 Kg
c).	after 75 h + 90°	"	"	"	47.25 Kg
d).	after 150h +120°	"	"	"	59.50 Kg
e).	after 300h +150°	"	"	"	57.50 Kg
f).	after 115h +180°	"	"	"	60.00 Kg

Adhesive: RTV 602 with 0.5 hardener (Figure 10).

a).	pre-storage test - average	adhesive	strength		39.25 Kg
b).	after 24 h - 80°	"	"	"	46.00 Kg
c).	after 75 h + 90°	"	"	"	24.25 Kg
d).	after 150h +120°	"	"	"	39.25 Kg
e).	after 300h +150°	"	"	"	56.00 Kg
f).	after 115h +180°	"	"	"	43.20 Kg

4.5. ADHESIVES FOR CEMENTING COVER GLASSES TO SOLAR BATTERIES /21

Test: End Pull Test

Sample: Transfer of force as for 4.3., 4.4.

Test values: Result in Kg force per 4 cm^2 solar battery surface.

Adhesive: XR-63-489 with 10% hardener (Figure 11).

a).	pre-storage test -	average	adhesive	strength	35.50 Kg force
b).	after 24 h - 80°	"	"	"	40.10 Kg
c).	after 75 h + 90°	"	"	"	22.50 Kg
d).	after 150h +120°	"	"	"	37.25 Kg
e).	after 300h +150°	"	"	"	30.25 Kg
f).	after 115h +180°	"	"	"	59.60 Kg

Adhesive: RTV 602 with 0.5% hardener (Figure 12).

a).	pre-storage test -	average	adhesive	strength	54.75 Kg
b).	after 24 h - 80°	"	"	"	51.50 Kg
c).	after 75 h + 90°	"	"	"	41.25 Kg
d).	after 150h +120°	"	"	"	44.25 Kg
e).	after 300h +150°	"	"	"	42.00 Kg
f).	after 115h +180°	"	"	"	60.00 Kg

5. DISCUSSION ABOUT THE CEMENTING RESULTS /22

Since, as already mentioned, the end pull testing gave very high values for all adhesives in the preliminary tests, the peel was chosen as criteria for selection. The Dow Corning S 2288 adhesive with 10% A 4,000 gave the best results for the storage test. The Wacker Company E 33 adhesive has similar properties. It was tested along with the others as an alternative adhesive of German manufacture, since maintaining supplies is very critical for the American adhesives due to the short storage stability and the long shipping time. The DC XR 63-489 cover glass adhesive has very good adhesive strength on Kapton for the end pull samples and is therefore also suitable for purely mechanical adhesive applications.

The tests have shown that all the adhesives have sufficient adhesive strengths at the required temperatures. The very low value of E 33 adhesive for Kapton on silver after the -80°C test is evidently due to the sensitivity of the adhesive to methanol vapor, which could have penetrated from the cooling system of the sample storage. S 2288 gave reduced strength for the peel test at over 120°C; this was also true to a smaller degree for DC XR 63-489. However, DC XR 63-489 shows a slight increase in strength for the end pull test. E 33 adhesive shows greater fluctuations in the peel tests.

S 2288 DC adhesive, inserted for a test panel after the result of the preliminary tests, is difficult to process. It is difficult to obtain a shrinkage-free cementing of the solar battery with a panel because of the prolonged pre-hardening times during degassing. However, a shrinkage-free cementing is important as a prerequisite for good thermal contact during radiation of the module with 11 solar constants. Also, its slight elasticity after hardening seems to hinder its thermal expansion in the modular assembly, and to lead to high mechanical demands of the module, as shown by the experience with the test panel. /23

According to the experience with the test panel, the results with XR 63-489 during the re-checking of the tested adhesives give the best consistancy of measurement with regard to the demands for

1. High elasticity
2. Easy shrinkproof processing
3. Sufficient strength at all temperatures

The low peel strength is without significance for rigid panels, since no peeling loads can occur; for the end pull test, an extraordinary good strength value was obtained with increasing tendency after +180°C with 35 kg force/battery.

Another panel with this adhesive showed excellent results after a test of 25 hours at -80°C; 100 hours at + 150°C and 1,000 hours at + 180°C.

For the high radiation intensities that occur, a good thermal contact is necessary over the whole surface of the solar batteries between the solar batteries and the panel, which can only be attained with a well processable adhesive which yields shrinkproof cementing.

With the occurence of thermally conditioned large expansions, an adhesive is also required which has good elasticity after curing.

On the basis of these two aspects the adhesive S 2288 is not as suitable as would be expected from the high strength values.

Because of these additional aspects, the adhesive DC XR 63-489 has to be assigned the advantage, even though it does not attain such high strengths in the peel test.

Adhesive: XR 63-489 Cementing Kapton/Al Test: Peel

/24

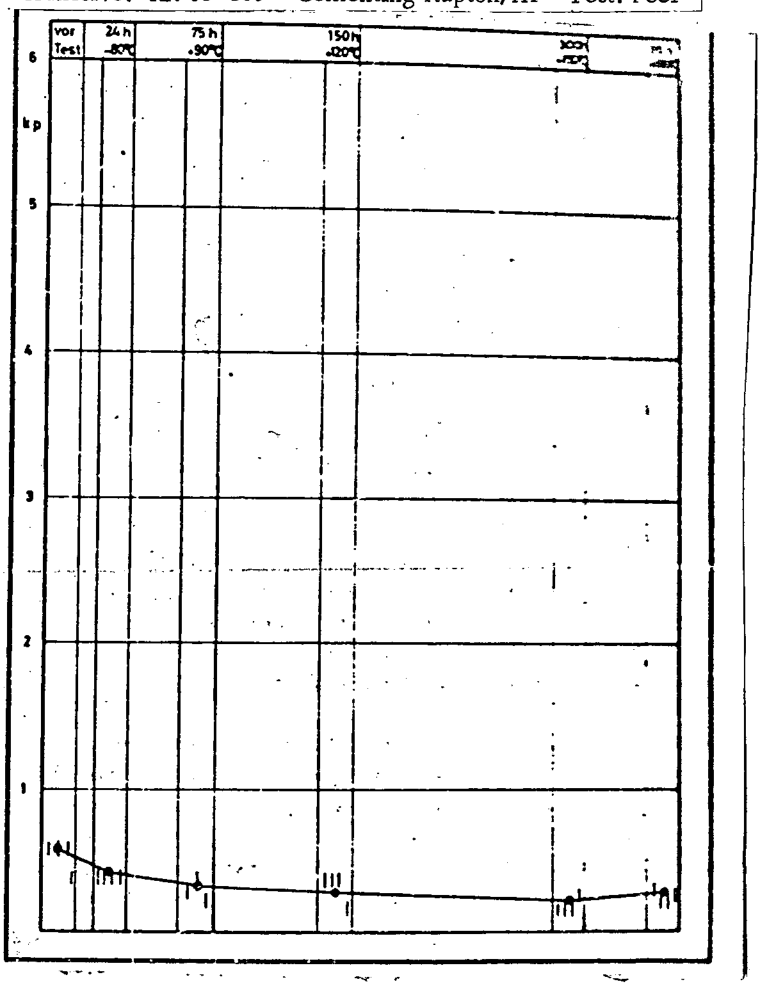

Figure 1. Temperature Test on Solar Battery Adhesives

Adhesive: E 33 Cementing Kapton/Battery Test: Peel

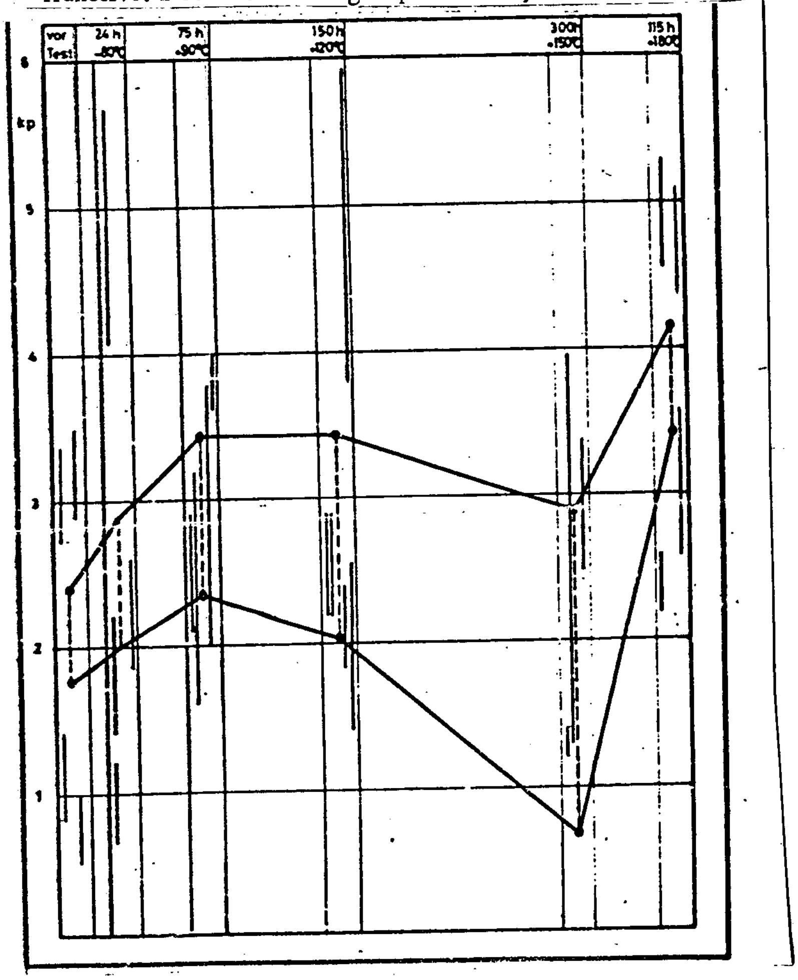

Figure 2. Temperature Test on Solar Battery Adhesives

Adhesive: 2288 10%A 4000 Cementing Kapton/Al Test: Peel

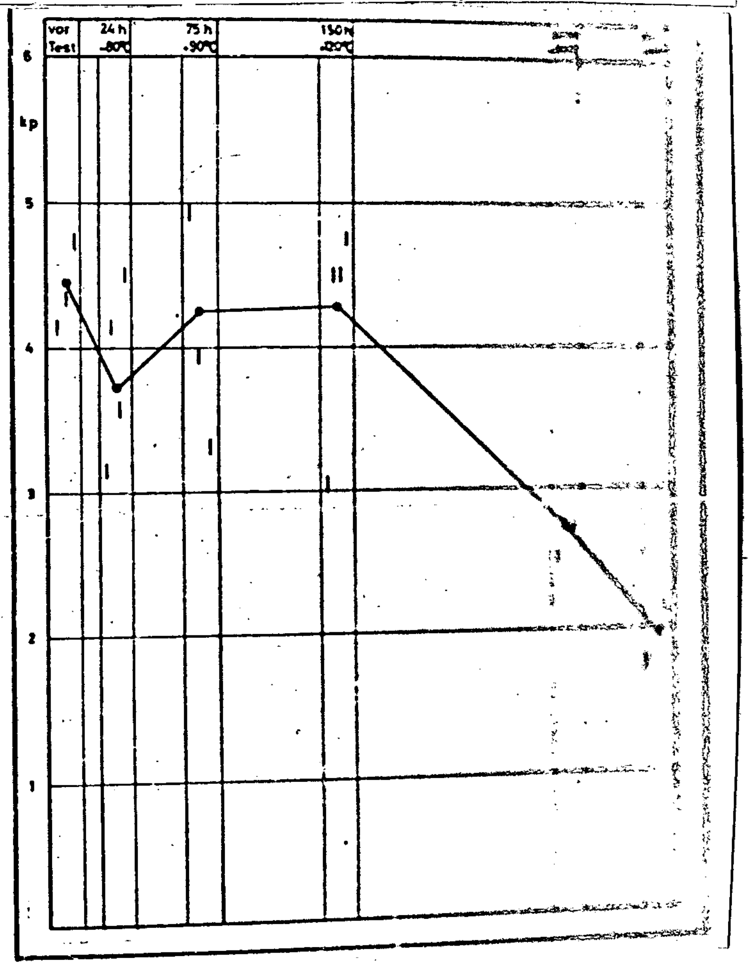

Figure 3. Temperature Test on Solar Battery Adhesives

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Adhesive: XR 63-489 Cementing Kapton/Silver Test: Peel

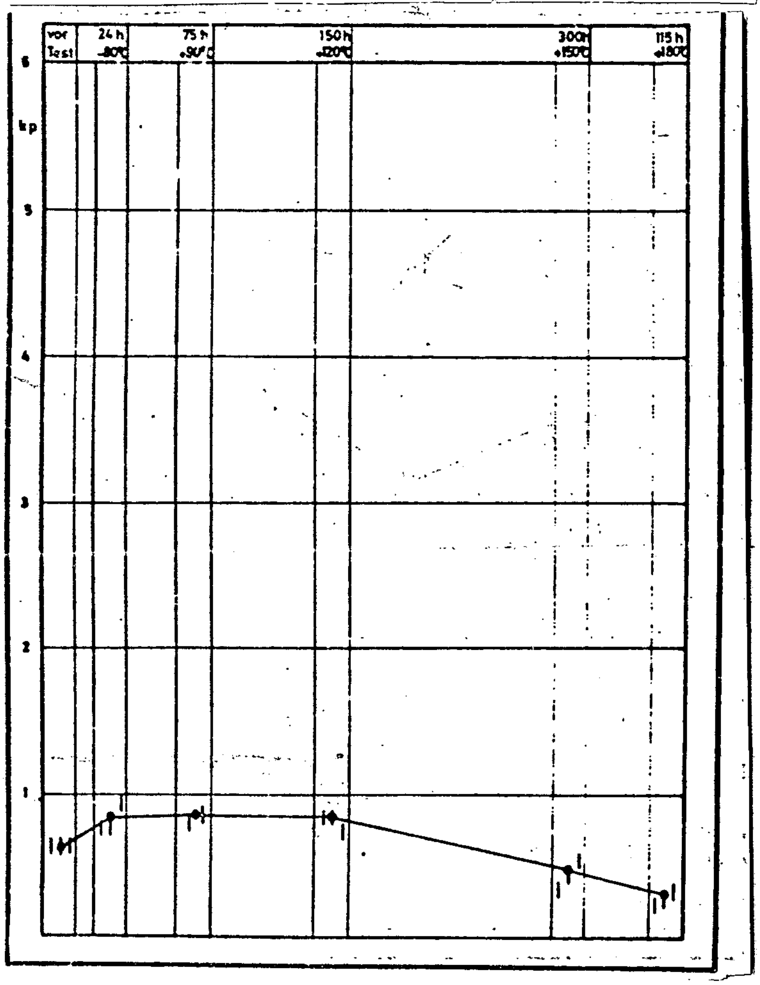

Figure 4. Temperature Test on Solar Battery Adhesives

/28

Adhesive: E 33   Cementing Kapton/Silver   Test: Peel

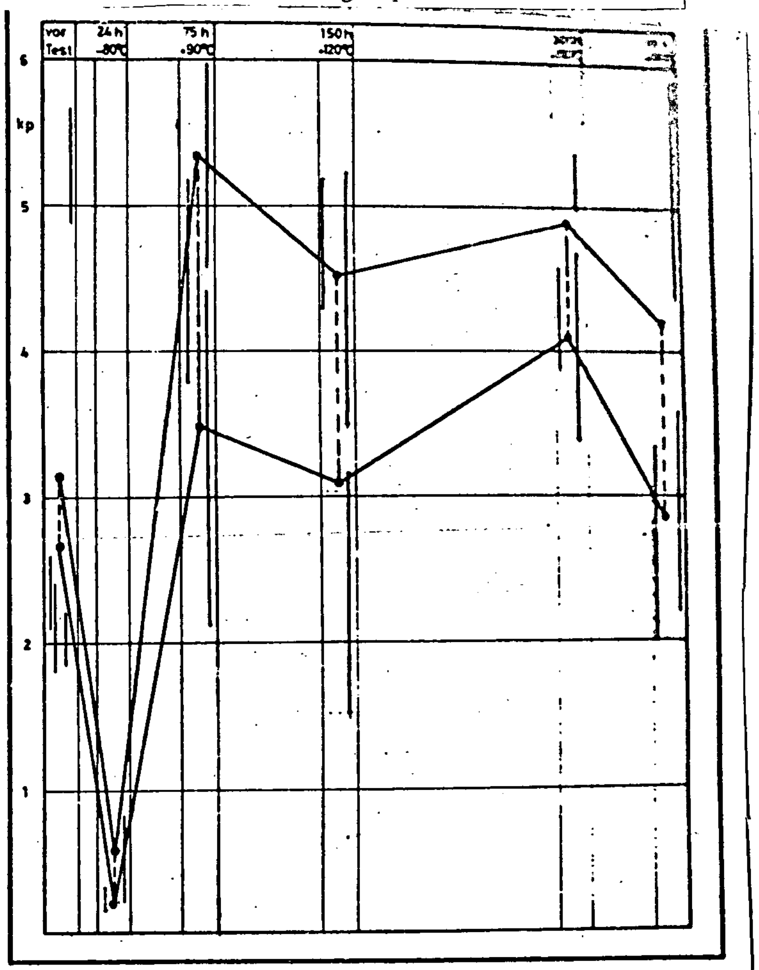

Figure 5. Temperature Test on Solar Battery Adhesives

Adhesive: 2288/10%A 4000 Cementing Kapton/Silver Test: Peel /29

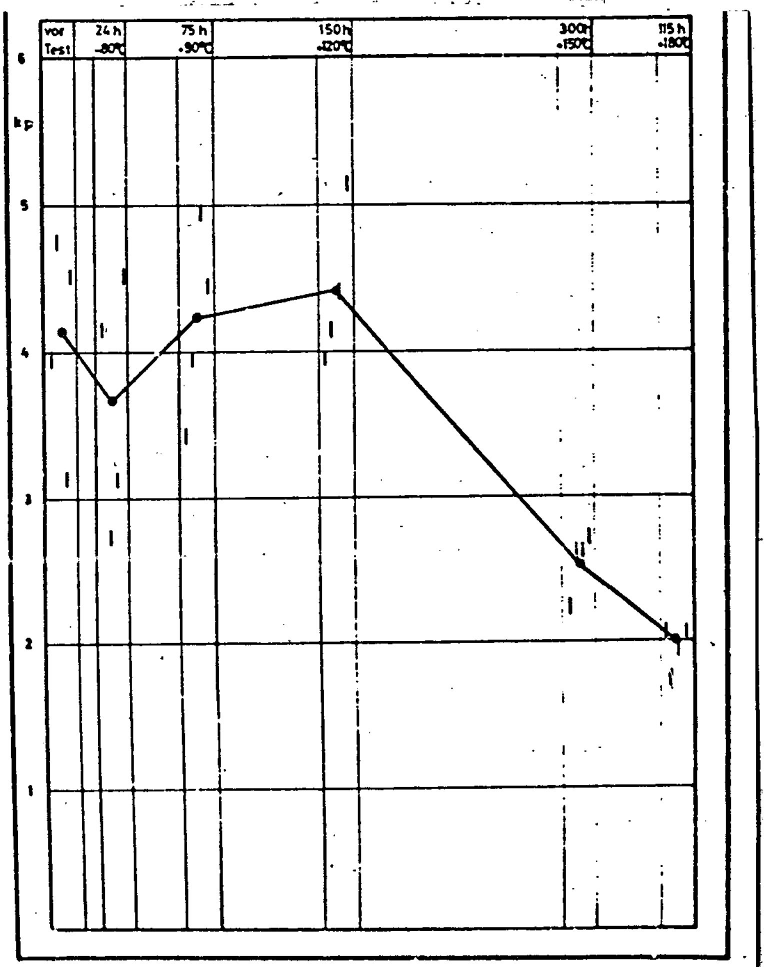

Figure 6. Temperature Test on Solar Battery Adhesives

Adhesive: XR 63-489 Cementing Kapton/Battery Test: End Pull

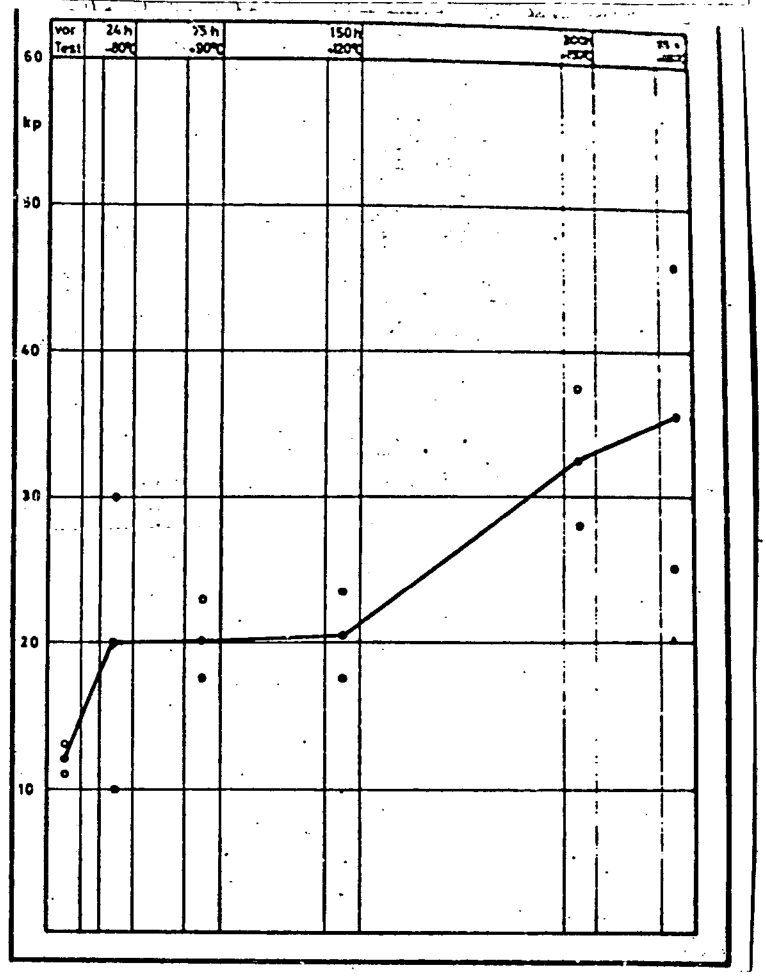

Figure 7. Temperature Test on Solar Battery Adhesives

Adhesive: E 33 Cementing Kapton/Battery Test: End Pull /31

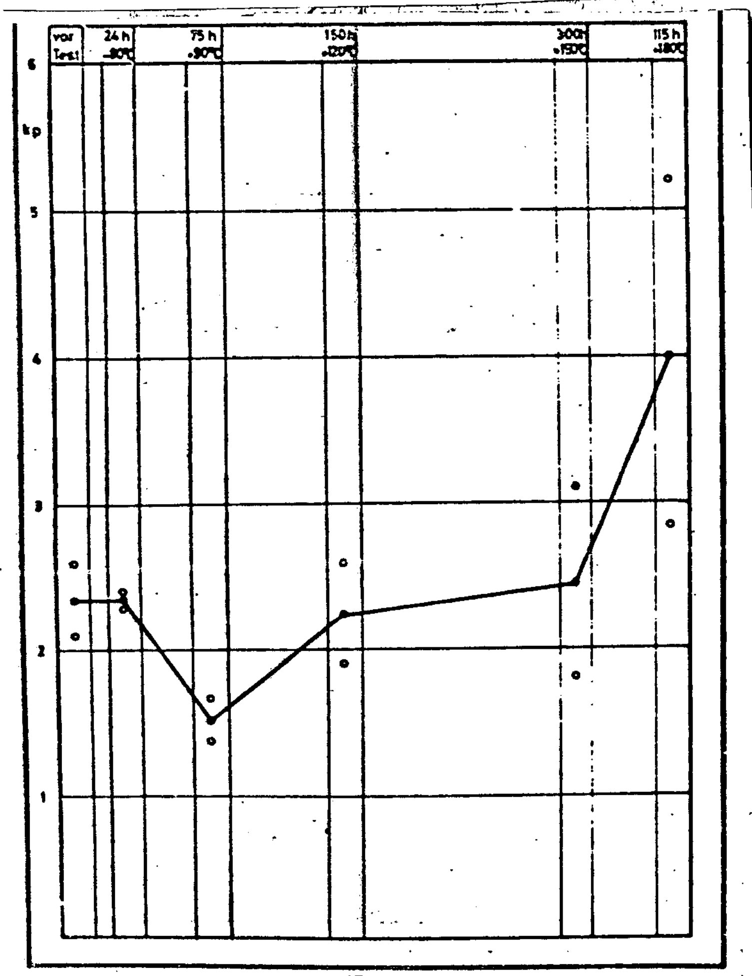

Figure 8. Temperature Test on Solar Battery Adhesives

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Adhesive: XR 63-489 Cementing Glass/Glass Test: End Pull

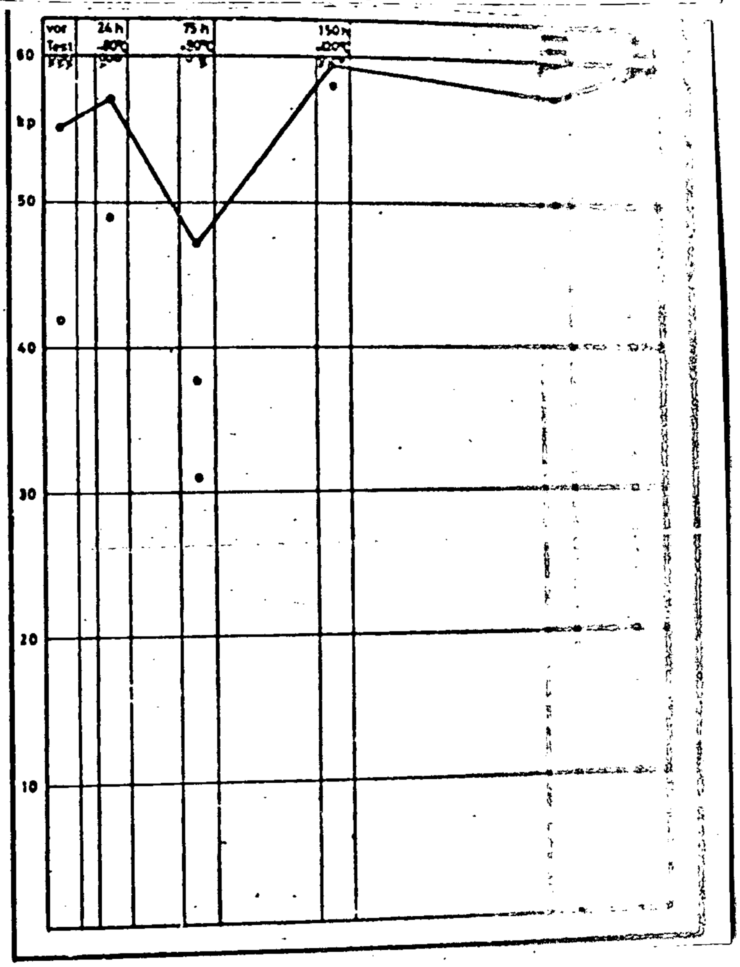

Figure 9. Temperature Test on Solar Battery Adhesives

Adhesive: RTV 602   Cementing Glass/Glass   Test: End Pull /33

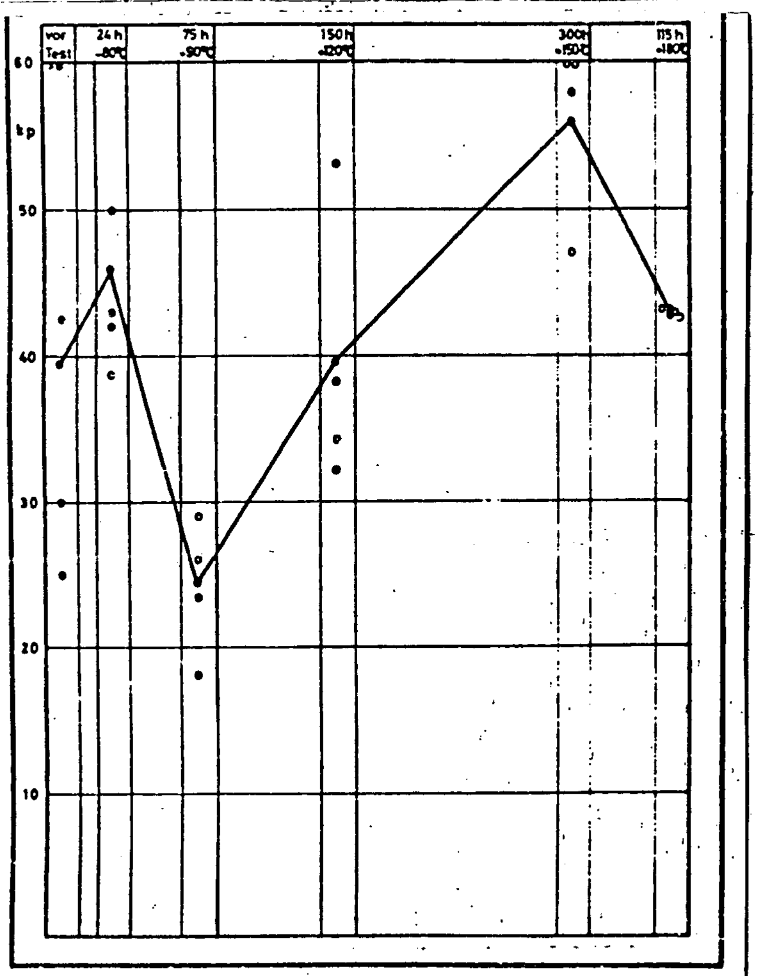

Figure 10. Temperature Test on Solar Battery Adhesives

Adhesive: XR 63-489 Cementing Battery/Cover Glass Test: End Pull /34

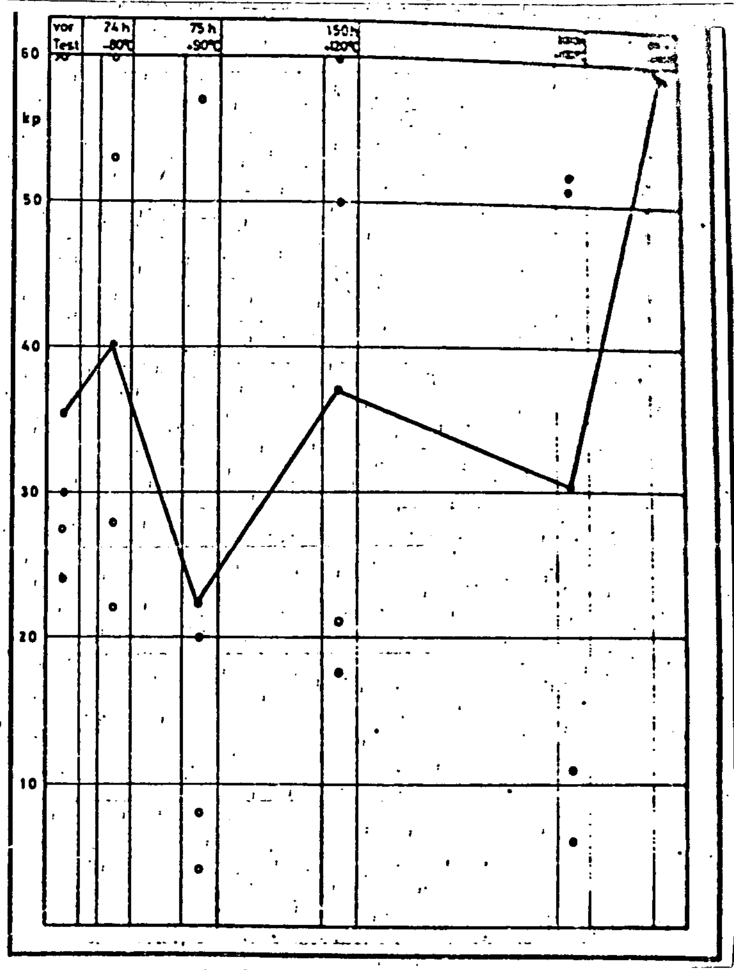

Figure 11. Temperature Test on Solar Battery Adhesives

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Adhesive: RTV 602 Cementing Battery/Cover Glass Test: End Pull

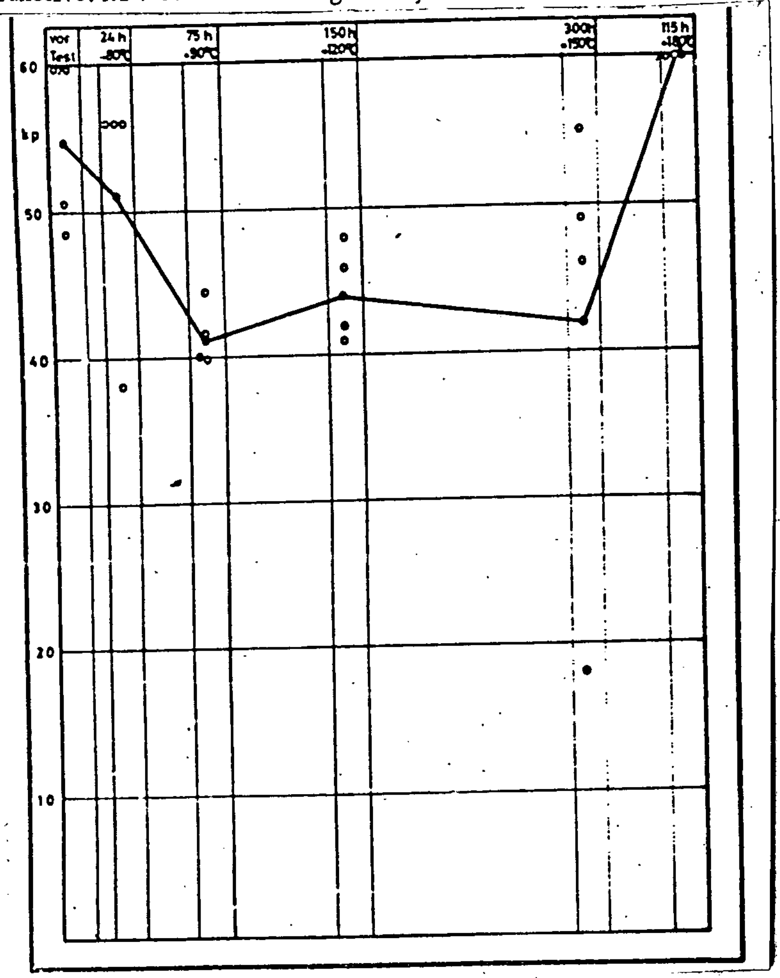

Figure 12. Temperature Test on Solar Battery Adhesives

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